

Reply Comments (Addendum)
FCC 98-208 Notice of Inquiry
in the Matter of Revision of Part 15 of the Commission's Rules
Regarding Ultra-Wideband Transmission Systems

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TEM Innovations wishes to submit this addendum, in consideration of the extension granted, to its Reply Comments submitted on January 2, 1999, to address the thrust of certain comments regarding UWB impulse radio.

IN FURTHER REPLY:

The FAA and the GPS Industry Council (to name a few) raised valid objections to UWB operation in restricted bands. Against this, numerous Comments expressed the need for a new spread spectrum radio capable of very high data rates, and several UWB radio proponents suggested that UWB impulse radio is the answer to these dreams. Nothing could be further from the truth. I am providing this input to the FCC to bring an independent perspective to the extravagant claims made by UWB radio proponents—claims that err by 100x in some cases, 1000x in others, and 100-billion-x in at least one case. The airwaves must be safeguarded by prohibiting the use of UWB impulse radio for communications.

By way of qualification, I'm an electronics engineer (MSEE) with 30 years experience in sub-nanosecond technology and a career that includes laser rangefinder work for an Apollo landing, short-pulse radar altimeter development work for the first Mars Lander, electronic warfare design for fighter aircraft with a major aerospace manufacturer, and more recently the invention of Micropower Impulse Radar (MIR), which became one of the most licensed technologies to emerge from Lawrence Livermore National Laboratory. I hold 35 patents in sub-nanosecond electronics and UWB radar, six of which are in UWB receiver sampling technology—and I have a dozen more patents pending in wideband RF technology.

UWB technology has enabled unique, vital applications including subsurface imaging radar such as GPR, civil engineering radar, landmine detection radar, and building construction radar. All these applications rely on UWB impulse transmissions that have no simple alternatives.

In contrast, UWB radio is a “me too” technology that pretends to compete with already existing, proven, reliable spread-spectrum radio services that are well-grounded in theory and practice. Technically, impulse radio is so far off-base that one has to wonder how it could be seriously promoted by any professional (see attachment 1, “The Myths of UWB Impulse Radio”). Apart from my public knowledge of the failure of UWB impulse radio to see use in the military, my own commercial effort to develop a certain UWB product made me aware of the impossibility of overcoming UWB’s broad vulnerability to everyday interference (for an example, see Attachment 2).

I urge the FCC to simply try to use a GPS receiver within 30 feet of a UWB impulse radio or conversely, to use a UWB impulse radio within a few hundred feet of a cell or PCS phone, or a microwave oven.

Impulse radio is a 30-year old idea that never went anywhere because it is fatally flawed—and it violates a fundamental law of information theory. It does not provide any compelling use of valuable radio spectrum—rather, we can all expect it to create “a decrease in safety margin” at airports, according to the FAA’s Comments, and to cause widespread disruption of the Global Positioning System, to say the least. The FCC should not waste taxpayers’ money considering it; nor should it grant waivers to a technology with no merit.

Sincerely,

A handwritten signature in black ink, appearing to read "Thomas E. McEwan". The signature is fluid and cursive, with a long horizontal stroke at the end.

Thomas E. McEwan

Attachments

ATTACHMENT 1

THE MYTHS OF UWB IMPULSE RADIO

- 1. Myth:** *UWB impulse radio offers extremely high process gains, set by the ratio of the RF bandwidth to the signal bandwidth. Process gains of 100,000 (50dB) are easily obtainable.*

Reality / Risk:

Process gain is *not* set by the RF bandwidth; it *is* set by the ratio of its impulse rate—which is equivalent to the chip rate in a direct sequence spread spectrum (DSSS) system—to its data rate. Since UWB bandwidths are ~1GHz and its impulse rates are usually ~1MHz, this myth overclaims UWB process gain by 1000x.

Note that the 1000x extra bandwidth is not needed and is in fact spurious from the standpoint of process gain. UWB systems used for the sake of “process gain” are *unnecessary noisemakers*.

- 2. Myth:** *UWB impulse radio signals propagate great distances on microwatts and don't require high peak powers.*

Reality / Risk:

All radio systems are subject to the same path loss physics. Regarding propagation records, the current amateur radio record is 1.9 million miles-per-watt (including ionospheric bounce). That's 1.9-miles per microwatt. UWB radio proponents have claimed ~1-mile per milliwatt, or *1900x worse* than amateur art.

It is theoretically impossible for UWB impulse radio to match the performance of a CW spread spectrum radio of the same peak power and same data rate because the extreme bandwidth of a UWB receiver raises its noise floor, typically more than 30dB, compared to a CW system. Accordingly, a CW radio of the same peak power and data rate as an UWB impulse radio will have at least 30x greater range. And that is without interfering with the restricted bands or being interfered-with by nearly every spectrum user on the airwaves. Conversely, the only way UWB impulse radio would have a chance against other spectrum users is to overpower all of them by transmitting high voltage impulses. At least some UWB radio proponents have used avalanche transistor impulse transmitters operating on 100's of volts, presumably in an attempt to overcome this UWB radio flaw.

- 3. Myth:** *UWB impulse radio is immune to interference and is anti-jam (AJ).*

Reality / Risk:

The exact opposite is true—UWB receivers are *extremely* susceptible to jamming. A UWB receiver is like a conventional RF receiver stripped of its RF and IF filters.

Elementary calculations show that a cell phone will create a 0.1mV receiver signal at 5.3km range, assuming omni antennas. That is a very high level by receiver standards—"6dB over S-9" on a signal strength meter. A UWB receiver will produce 0.1mV samples in response to the cell phone (not to mention the additive effect of all the other cell phones, TV stations, microwave ovens, etc. within tens of km). Similarly, the UWB receiver will produce 0.1mV samples from a UWB transmitter of the same peak power and range.

Each sample represents the sum of the desired and the interfering signals at the exact instant of sampling. Once a sample is taken there is no way to tell what portion of the sample is from the desired signal and what portion is from the interference.

Time-position coding of the exact time that samples are taken is of no help in reducing random interference (all external interference is inherently random). "Random" means unpredictable, and no amount of "intelligent" sample timing will make random interference samples predictable and subject to cancellation. A UWB receiver's only weapon against interference is sample averaging—and that is a major flaw.

Published UWB radio systems suggest sample integration (i.e., averaging) to reduce the huge jumble of sampled interference—an incredibly slow and inefficient process. For example, if 100 samples are averaged into one equivalent sample, the effect of interference on the averaged sample is reduced by 10x, or a scant *20dB at the expense of a 100-to-1 reduction in data rate*. And that 20dB is the UWB system's total defense against "everything that's out there."

A practical UWB impulse communications receiver would need at least 80dB of interference rejection (120dB would be better) and accordingly would need to average 100-million samples (120dB or 1-trillion samples would be better). Given a typical ~1MHz UWB pulse rate, a minimally practical UWB communications system can support a data rate of 0.01 bits per second, not even astronomically close to the 1000Mb/s being bandied about by UWB radio proponents (a discrepancy of a mere 100-billion! At a more practical 120dB of interference rejection the discrepancy rises to a truly astronomical 100,000-billion-x.).

There is no way around this intrinsic deficiency. A UWB impulse receiver is a sampling device that is subject to the same Nyquist sampling theorem as any other sampling device, such as an A/D converter—you must sample at least twice the frequency of the incoming signal to adequately represent it and to avoid aliasing. Since a UWB receiver samples ~1GHz interference signals at ~1MHz rates, the interference is *2000x undersampled* and, as a consequence, it is *theoretically* impossible to coherently filter or reject interference after sampling. There just aren't enough samples taken—at least 2000x too few. The only option available to reduce noise and interference is a poor one—working with averages.

In contrast, the RF and IF filters in conventional radio technology provide the necessary Nyquist filtering. Unlike UWB impulse radio, CW radios, including spread spectrum radios, do not violate fundamental information theory.

In the presence of interference, a UWB impulse receiver is similar to an old crystal radio set that simultaneously detects more than one station at a time, and the only

option to combat the problem is to ineptly muffle the headphones or turn down the tone control (equivalent to sample averaging). The problem is, UWB impulse radio combines the various interference sources into single samples and there is no way to separate them out afterwards to get the desired signal (violation of the Nyquist sampling theorem).

4. Myth: *UWB impulse radio code correlators will enable a huge number of channels.*

Reality / Risk:

First, the UWB RF system has to screen-out interference, and it clearly doesn't. Multi-channel orthogonal code correlators work well with a digital bit stream having a steady clock and an embedded code. Correlators are basically useless in filtering samples of random broadband RF present at the terminals of a UWB antenna. They are absolutely no substitute for sharp-cutting, multipole RF and IF filters. A correlator's integrator is basically a single-pole filter with no better selectivity than an old-time crystal radio set. Code correlators are no Band-Aid for an extremely poor RF line-up and they will not enable new impulse UWB communication channels.

5. Myth: *UWB impulse radio is covert. It is 100dB less likely to be intercepted than conventional technology, particularly when pulse position modulated.*

Reality / Risk:

Any receiver with 30MHz bandwidth can detect impulse transmissions. Spectrum analyzers with 30MHz bandwidth are commercially available for use as UWB intercept receivers.

A 30MHz-bandwidth intercept receiver will be desensitized by 34dB when receiving a 0.5ns impulse, but it will also have a 17dB lower noise floor than a 0.5ns UWB receiver due to its lower bandwidth—a noise factor that appears to be overlooked by many UWB proponents. Thus, the UWB system is “undetectable” by only 17dB, not 34dB. That 17dB advantage can quickly vanish with a directional intercept antenna or by operating at closer range.

A further advantage for the intercept receiver is that it can be tuned to any vacant 30MHz slot out of the 2GHz UWB spectrum, whereas the UWB receiver is subject to interference from every emitter in that same 2GHz band. The intercept receiver easily avoids interference, whereas the UWB receiver is wide open to interference.

Pulse position modulation will not make the UWB system any stealthier when the UWB pulse rate is less than 30MHz—the intercept receiver will respond to each individual impulse. Since most impulse systems operate at a few megahertz pulse rate, pulse position dithering will not change the amplitude of the detected UWB pulses. Rather, the intercept receiver will detect each pulse in the UWB data stream for subsequent de-encryption.

- 6. Myth:** *UWB impulse radio receivers are as sensitive as conventional receivers, and can pull signals out of the noise.*

Reality / Risk:

UWB receivers don't listen 99.9% of the time (typically), due to their low duty-cycle. If people didn't listen 99.9% of the time they would have a serious communication problem, and UWB receivers are no different—they are extremely inefficient. This inefficiency translates into extremely high input noise, scaling in inverse proportion to the duty-cycle. Consequently, a UWB receiver requires a very strong signal level.

The wide bandwidth of a UWB receiver further increases its input noise, an obvious fact that appears to have been ignored by UWB radio proponents in their process gain calculations. At 3GHz bandwidth, a UWB receiver will have a whopping -79dBm theoretical minimum noise floor, equivalent to an S-8 on a signal strength meter. After adding a 20dB margin for reliable signal detection, a UWB radio link would require an equivalent peak signal level of at least 10 dB over S-9 just to operate at minimum functionality.

The impact of UWB receiver noise can be placed in a system-level context. While decreasing the UWB transmitted impulse width spreads its spectrum, receiver sensitivity drops in the same proportion due to its increase in required bandwidth. Thus, impulse radio is a zero sum relation. There is no “process gain” in artificially spreading bandwidth beyond that required to support the data or chip rate—only the deleterious side effects of creating unnecessary radiation into the restricted bands and raising a vast susceptibility to interference from nearly every spectrum user.

Regarding averaging, any receiver can pull pulses out of the noise by averaging pulses, but averaging doesn't change the fact that it is a conceptually poor receiver. A UWB receiver with a 0.1% duty-cycle would need to average 1000 pulses just to break even with the sensitivity of a CW spread-spectrum receiver.

- 7. Myth:** *UWB impulse radio is immune to multi-path effects.*

Reality / Risk:

Common multi-path effects can only be countered with extremely high bandwidth systems with center frequencies that don't propagate well through walls.

If a radio link is spaced 2-feet away from a 100-foot wall, the multi-path length off the wall is 100.08-feet, only 0.08-feet longer than the direct path. A half-wavelength of 0.08-feet corresponds to 6.25GHz, so the UWB center frequency needs to be substantially higher, at least 12GHz to reduce multi-path effects.

Since 12GHz signals don't penetrate walls very well, a 12GHz radio would make an unreliable through-wall data link. Obviously, an impulse radio operating at 2GHz center frequency will not overcome common multi-path problems. The raw bandwidth of UWB radio is simply not a solution to indoor multi-path problems.

CONCLUSION

While UWB technology has unique, valid applications in imaging and sensing, UWB impulse radio is an old, fatally flawed idea. It violates a fundamental tenet of information theory and offers nothing but interference to vital spectrum users, including my company's sensors, while failing to provide any advantage to its customers or redeeming value to the public. UWB radio was openly proposed three decades ago, yet none of the major radio houses, such as Motorola or Rockwell Collins, have picked up on it. Maybe their engineers don't believe in myths.

Perhaps the FCC, financial investors, and proponents considering UWB impulse radio as the "Holy Grail" should confer with these two companies for their patriotic and professional advice, which may help the communication industry avoid major mishaps. In my opinion, it would be a grievous mistake to populate the airwaves with even a small number of UWB impulse radio systems. They may cause a serious mishap before the GPS community and the FAA can move to outlaw them in the same fashion as another novel but equally threatening technology was outlawed: "Spark Gap Transmitters" of an earlier era (which were banned internationally). There will no doubt be equivalent objections to UWB impulse radio from the international community.

ATTACHMENT 2

EXAMPLE OF CELL PHONE INTERFERENCE TO A UWB RADAR

I recently adapted a Micropower Impulse Radar (MIR) motion sensor to operate as a close-range guitar string pickup. It was to be a substantial upgrade to the antiquated magnetic pickups used in steel guitars (a \$500M/year market) that are susceptible to 60-Hertz hum and have limited bandwidth and fidelity. The MIR pickup worked very well and provided a 90dB signal-to-noise ratio. Most importantly, it wasn't susceptible to magnetic interference.

The MIR pickup was range-gated to eliminate 120-Hertz interference from florescent lamps, which 2GHz radar waves readily reflect from. A range gate of one-foot was used with a resulting need for about 500MHz of bandwidth. The MIR transmitter was a short-pulse RF oscillator (non-impulse) with emissions centered in the 1.72-2.2GHz §15.209 band, and the receiver operated as a UWB integrating sampler running at a 10MHz sample rate.

During an attempted recording session, the radar pickup did more than pick up the guitar strings—scratchy voice segments randomly popped out of the speakers. It quickly became clear that the radar was picking up cell phones from people in cars that were moving from cell-to-cell. Needless to say, the recording session was ruined and the concept of a UWB radar guitar was not to be.

The failed UWB radar guitar pickup was operated at a similar pulse rate (10MHz), RF frequency (~2GHz), signal bandwidth (16kHz), and with a similar amount of pulse averaging (100 samples) as seen in currently proposed UWB impulse radio systems. Similarly, the proposed UWB impulse radio systems will have the same susceptibility to cell and PCS phone interference (not to mention the aggregate effect of microwave ovens, UHF TV stations, ham radio transmissions, wireless LANs, etc.).

Unfortunately, there is no way to overcome this theoretical and actual deficiency of UWB impulse radio to interference from everyday spectrum users. And this is surely why none of the RF experts in the communications industry have pursued this fatally flawed technology (not to mention its generation of widespread interference).